

1 **Method And Apparatus For Adapting An Information Carrying**
2 **Signal**

3
4 This invention relates to the field of communications
5 systems. More particularly, this invention relates to a
6 method and apparatus for adapting an information carrying
7 signal. The method and apparatus can be readily employed
8 within a transmitter of a communication system so as to
9 overcome signal impairment effects within the system.
10 The invention has particular use as an equalisation
11 element in the field of fibre optic communications
12 networks to counteract dispersion and other complex
13 signal impairments.

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15
16 **Background Art**

17
18 Electronically adjustable equalization transmitter
19 schemes for communications systems are well known in the
20 art. Such a scheme is embodied in US Patent No. US
21 6,393,062 entitled "Methods and circuits for generating a
22 pre-emphasis waveform". This scheme relies on pre-
23 compensating a waveform by selectively boosting the
24 electronic signal to a value larger than the nominal

1 signal, essentially providing data-dependant pulse
2 amplitude modulation.

3
4 There are however several major drawbacks with this
5 scheme. In the first instance pulse amplitude modulation
6 is not a suitable control method for increasing the
7 optical intensity in order to provide compensation in an
8 optical fibre system because:

9 a) in standard systems amplitude information is
10 removed using a pre-laser limiting or clipping
11 function in order to simplify driver electronics;
12 and

13 b) lasers are very non-linear devices and so
14 amplitude modulation is non-linearly related to
15 optical intensity.

16
17 As a result lasers do not respond or do not respond well
18 to pulse amplitude modulation.

19
20 Secondly, with higher data-rate signals, for example
21 greater than 10 Gbps, such a scheme is very difficult to
22 practically implement in a low cost electronic CMOS or
23 BiCMOS silicon technologies as the required switching
24 speeds and slew rates will be unwieldy and difficult to
25 control accurately.

26
27 A further drawback is that the amplitude and settling
28 characteristics relied upon to perform the equalisation
29 are subject to unacceptable variations and so are not
30 suitable for precision or high speed applications. As
31 shown in a particular embodiment, the scheme requires
32 additional circuitry to accurately control the amount of
33 boost which in-turn increases complexity, power and cost
34 of the system.

1

2 Furthermore, the signal boosting scheme described
3 requires the driving of a larger than normal signal.
4 This may not always be possible given power supply
5 constraints or, conversely, requires some signal
6 amplitudes to be reduced, which does not maximise
7 available signal to noise available for these signals.

8

9 European Patent Application No. EP 0,884,867 describes a
10 system for "Equalization, pulse shaping and regeneration
11 of optical signals". In particular this document teaches
12 of an equalisation arrangement for use in optical systems
13 with optical fibre media. The scheme relies on
14 equalisation using weighted tap filters crafted so as to
15 employ optical components in the optical domain. Such an
16 approach again exhibits several inherent disadvantages.

17

18 Firstly, such equalisation can only compensate for linear
19 effects that contribute to Inter-Symbol-Interference
20 (ISI) such as those caused by dispersion. However, other
21 non-linear effects including laser and fibre chirp,
22 changes in fibre characteristics with optical intensity,
23 duty cycle distortions and unequal rise/fall times of the
24 transmitter or receiver are not addressed.

25

26 Secondly, the system is relatively expensive to make as
27 it relies on several expensive optical amplifiers,
28 optical monitors and customised and precise lengths of
29 delay matched optical fibres.

30

31 Thirdly, the physical size and inherent power
32 requirements make such schemes less desirable or
33 practical in modern installations.

34

1 It is an object of an aspect of the present invention to
2 provide a method and apparatus for filtering an
3 information carrying signal. In particular this method
4 and apparatus can be employed for equalisation of the
5 information carrying signal so as to overcome the
6 problematic features of the prior art.

7
8
9 **Statements of Invention**

10
11 According to a first aspect of the present invention
12 there is provided a method of adapting an information
13 carrying signal that comprises a plurality of data pulses
14 that exhibit a range of pulsewidths and which are
15 generated by a transmitter for transmission through a
16 propagation medium, the method comprising the step of
17 introducing one or more sub-pulses to one or more of the
18 plurality of data pulses prior to the information
19 carrying signal entering the signal propagation medium
20 wherein a pulsewidth of each of the one or more sub-
21 pulses is less than a minimum pulsewidth of the plurality
22 of data pulses.

23
24 The introduction of the one or more sub-pulses whose
25 pulse width is less than the minimum pulse width of the
26 plurality of data pulses allows for the energy contained
27 within the plurality of data pulses to be altered thus
28 providing a means for the information carrying signal to
29 be controllably adapted.

30
31 Most preferably an amplitude of the one or more sub-
32 pulses is of an opposite sign to an amplitude of an
33 associated data pulse.

34

1

2 Preferably the introduction of one or more of the sub-
3 pulses are timed so that these sub-pulses are contained
4 within one or more of the plurality of data pulses to
5 which the sub-pulses are introduced.

6

7 Preferably the introduction of one or of the more sub-
8 pulses are timed so that these sub-pulses coincide with
9 one or more edges of one or more of the plurality of data
10 pulses to which the sub-pulses are introduced.

11

12 Preferably, the one or more sub-pulses are introduced to
13 one or more of the plurality of data pulses when the data
14 pulse exhibits a pulsewidth above a first predetermined
15 pulsewidth of the plurality of data pulses so as to
16 provide a means for low frequency filtering the
17 information carrying signal.

18

19 Alternatively, the one or more sub-pulses are introduced
20 to one or more of the plurality of data pulses when the
21 data pulse exhibits a pulsewidth below a second
22 predetermined pulsewidth of the plurality of data pulses
23 so as to provide a means for high frequency filtering the
24 information carrying signal.

25

26 Most preferably the first predetermined pulsewidths of
27 the plurality of data pulses corresponds to the minimum
28 pulsewidth of the plurality of data pulses so as to
29 provide a means for equalising the information carrying
30 signal.

31

32 It is known that attenuation of a data signal is
33 frequency or pulsewidth dependent i.e. the higher the
34 frequency the greater the attenuation experienced. Thus

1 by employing the sub-pulses to effectively remove energy
2 from the lower frequency components of the data signal
3 equalisation of the data signal following transmission
4 through a propagation medium is achieved.

5

6 Preferably the timing of introducing the one or more sub-
7 pulses to one or more of the plurality of data pulses is
8 variable.

9

10 Most preferably, the number of sub-pulses introduced is
11 directly dependent upon the pulsewidth of the associated
12 data pulse. Alternatively, the pulsewidth of the one or
13 more sub-pulses is directly dependent upon the pulsewidth
14 of the associated data pulse.

15

16 Preferably the coinciding of the one or more sub-pulses
17 with one or more edges of one or more of the plurality of
18 data pulses acts to time shift a rising and/or a falling
19 edge of an associated data pulse.

20

21 Optionally the time shifting of the rising and/or the
22 falling edge of the associated data pulse is by a
23 predetermined value. Alternatively, the time shifting of
24 the rising and/or the falling edge of the associated data
25 pulse is directly dependent upon the pulsewidth of the
26 associated data pulse.

27

28 Preferably the time shifting of the rising edge of an
29 associated data pulse comprises advancing in time the
30 rising edge.

31

32 Preferably the time shifting of the falling edge of an
33 associated data pulse comprises delaying in time the
34 falling edge.

1 According to a second aspect of the present invention
2 there is provided an electronic circuit suitable for
3 adapting an electronic input signal of a transmitter, the
4 electronic input signal comprising a plurality of
5 electrical data pulses, the electronic circuit comprises
6 an electronic input channel, a clock pulse phase delay
7 circuit, a signal processor and an electronic output
8 channel wherein the signal processor analyses one or more
9 of the plurality of electrical data pulses supplied on
10 the electronic input channel and one or more clock pulse
11 phase delay signals provided by the clock pulse phase
12 delay circuit so as to introduce one or more electrical
13 sub-pulses to one or more of the plurality of electrical
14 data pulses so as to provide an adapted electronic output
15 signal on the electronic output channel.

16
17 Preferably the introduction of one or more of the
18 electrical sub-pulses are timed so that these electrical
19 sub-pulses are contained within one or more of the
20 plurality of electrical data pulses to which the
21 electrical sub-pulses are introduced.

22
23 Preferably the introduction of one or more of the
24 electrical sub-pulses are timed so these electrical sub-
25 pulses coincide with one or more edges of one or more of
26 the plurality of electrical data pulses to which the
27 electrical sub-pulses are introduced.

28
29 Most preferably the clock pulse phase delay circuit
30 comprises means for supply a first clock pulse and one or
31 more phase delayed clock pulses to the signal processor.

32
33 Preferably the signal processor comprises first
34 electronic means for producing an internal signal pulse

1 when subsequent electrical data pulses exhibit
2 substantially the same value.

3

4 Preferably the signal processor further comprises a
5 second electronic means for introducing an electronic
6 sub-pulse to the electronic input signal when the
7 internal signal pulse is detected by the second
8 electronic means.

9

10 Preferably the signal processor further comprises a third
11 electronic means for altering the timing of the
12 electrical sub-pulses so allowing the sub-pulses to
13 coincide with a rising or falling edge of an electrical
14 data pulse.

15

16 Most preferably the timing of the first electronic means
17 is controlled by the first clock pulse.

18

19 Preferably the second and third electronic means are
20 controlled by the combination of the first clock pulse
21 and the one or more phase delayed clock pulses.

22

23

24 **Brief Description of Drawings**

25

26 In the following detailed description of the preferred
27 embodiments or mode, reference is made to the
28 accompanying drawings, which form part hereof, and in
29 which are shown, by way of illustration, specific
30 embodiments in which the invention may be practised. It
31 is to be understood that other embodiments may be
32 utilised and structural changes may be made without
33 departing from the scope of the present invention.

34

1 FIGURE 1 shows a system block diagram of a typical
2 communication channel that will be used for reference
3 purposes;

4

5 FIGURE 2 shows a system block diagram of a typical long-
6 haul fibre optic communication channel that incorporates
7 an adaptable signal processing element, shown within the
8 transmitter function, in accordance with an aspect of the
9 present invention;

10

11 FIGURE 3 shows an example of a standard transmitted (in)
12 and received (out) signal waveform before any wave signal
13 processing in the transmitter is applied;

14

15 FIGURE 4 shows the resulting "eye diagram" of the
16 information presented in Figure 3;

17

18 FIGURE 5 shows details of the operation of the adaptable
19 signal processing element employed to equalise the
20 received (out) signal waveform at the output of the
21 transmitter and in particular schematically presents
22 definitions of coefficient terms employed for achieving
23 this result.

24

25 FIGURE 6 shows an example of a modified transmitted (in)
26 and received (out) signal waveform after the adaptable
27 signal processing element within the transmitter is
28 applied;

29

30 FIGURE 7 shows the resulting improved "eye diagram" of
31 the information presented in Figure 6;

32

1 FIGURE 8 shows a top level schematic view of the
2 preferred embodiment of the adaptable signal processing
3 element;.

4
5 FIGURE 9 shows detail of the clock pulse signal waveforms
6 employed within the adaptable signal processing element
7 such that it operates to equalise the received (out)
8 signal waveform;

9
10 FIGURE 10 shows schematic detail of the signal processor
11 apparatus; and

12
13 FIGURE 11 shows details of the waveforms generated within
14 adaptable signal processing element of Figure 5.

15
16
17 **Detailed Description**

18
19 Adaptable schemes can be used in order to improve some
20 desired metric of a communications system's performance.
21 By improving the system performance an adaptable system
22 allows higher bandwidth or higher data-rate or longer
23 reach or more compact or less expensive systems to be
24 made.

25
26 A detailed description of the method and apparatus for
27 such an adaptable system shall now be described and in
28 particular to its employment as an equaliser for an
29 information carrying signal transmitted within an optical
30 system. This equalisation can be used to counteract
31 bandwidth limiting or other signal impairments within the
32 channel.

33

1 Within a communications system typical signal impairment
2 or degradation mechanisms include the rise time, fall
3 time, bandwidth or other distortion of the receiver or
4 transmitter, dispersion, chirp, reflection and bandwidth
5 limitations within the media and interference from other
6 signals. The words signal impairments or degradation
7 mechanism will be used extensively throughout this
8 document for any linear or non-linear, stationary or non-
9 stationary or other non-ideal affect anywhere in the
10 communications channel that causes the received signal to
11 be adversely affected.

12
13 The resultant effects of these degradation mechanisms on
14 the signal are often dependant on the inter-relationship
15 of the signal being transmitted and the degradation
16 mechanism itself. Within some bounds these are
17 repeatable effects. These will be generally referred to
18 as deterministic effects throughout this document.

19
20 The task of equalisation or compensation is to modify the
21 physical characteristics of an information carrying
22 signal in order to correct, accommodate or rectify some
23 impairment in it. In an aspect of the present invention
24 the equalisation is achieved by synthesising a new
25 transmitted wave-shape using a high speed signal
26 processor. This signal processing, synthesis and
27 resultant equalisation is achieved using a technique
28 whereby energy is added or subtracted to the wave shape
29 in the form of constructive or destructive sub-pulses
30 and/or by manipulating within the information carrying
31 signal individual pulse edge positions. The method and
32 apparatus for the preferred embodiment of this are as
33 follows.

34

1 A typical one-way communications system is shown in
2 Figure 1. The channel 6 transmits its input signal, in
3 1, via the transmitter 2, through the media 3, to the
4 receiver 4 and out in the form of output signal 5.

5
6 A typical long-haul fibre optic communication showing the
7 preferred embodiment is shown in Figure 2. The
8 transmitter 2 includes the adaptable signal processor 7
9 that provides for wave synthesis equalisation in front of
10 the optical source 8. The input signal 1, is modified by
11 the action of the adaptable signal processor to produce
12 the equalised electronic signal, ewave 25. The optical
13 source converts the electronic signal into an equivalent
14 optical signal, owave 26. The media 3, here an optical
15 fibre, itself is shown partitioned into smaller lengths
16 with optical amplifiers 11 used to boost the signal along
17 the length, as is typical of these systems, in order to
18 maximise transmission distances. Amplifiers or repeaters
19 11 are optionally required as the signal 1 becomes
20 attenuated with distance due to losses within the optical
21 fibre 3. The optical signal 26 is received at the
22 optical detector 9 and amplified to an electrical signal
23 by the post amp 10.

24
25 Figure 3 shows the time-domain input and output waveforms
26 of the entire communications system represented in Figure
27 2 when the signal processing element 7 is disabled. The
28 figure shows the input signal waveform 1 and the modestly
29 distorted output signal waveform 5 when no equalisation
30 or other correction is employed. Note that the exact
31 output waveform 5 is for illustrative purposes only and
32 more or less complex distortion can occur, and for this
33 purpose no random or further deterministic jitter is
34 shown. The waveforms drawn illustrate a non return to

1 zero (NRZ) signalling scheme which is most likely
2 implemented as a differential signal with the signal
3 swinging above (positive) and below (negative) the zero
4 axis. Where the signal is intended to be digital or
5 binary in nature the signals may be alternatively
6 represented by digital signals where a logical "one" is a
7 differentially positive signal and a logical "zero" is a
8 differentially negative signal.

9
10 Figure 4 shows an alternative and readily used time-
11 domain representation of the output waveform 5 as
12 described in Figure 3 and called an "eye-diagram". The
13 purpose of the post receiving stage (not shown) is to
14 determine the optimal sampling point, for example in the
15 middle of the "eye" 14 and decide whether a "one" or a
16 "zero" was sent. However making a decision on whether
17 the signal should be a "one" or a "zero" is made more
18 difficult by the data jitter 15 and eye closure 16. The
19 jitter 15 increases and the eye closes 16 due to a number
20 of impairment and degradation mechanisms. This commonly
21 manifests itself as inter-symbol interference as
22 neighbouring bit-patterns constructively or destructively
23 interfere.

24
25 Figure 5 shows a definition of a new input waveform
26 "wave", synthesised using the adaptable signal processor
27 7. The top waveform 25 drawn illustrates the electrical
28 signal, ewave 25, using a NRZ signalling scheme which is
29 most likely implemented as a differential signal with the
30 signal swinging above (+ve) and below (-ve) the zero
31 axis.

32
33 Where the signal is intended to be digital or binary in
34 nature the signals may be alternatively represented by

1 digital signals where a logical "one" is a differentially
2 positive signal and a logical "zero" is a differentially
3 negative signal.

4

5 The lower waveform in Figure 5 represents the resultant
6 optical output, owave 26, generated by the optical source
7 8. This waveform illustrates that the light is either on
8 or off as controlled by the electronic signal ewave 25.
9 Therefore, an important advantage of this scheme is
10 clearly visible in that this scheme does not at all rely
11 on any amplitude characteristic of the electronic signal
12 ewave 25 or intensity response from the optical source 8
13 to an electronic amplitude in order to achieve
14 equalisation. This is important as the optical source
15 driving electronics normally would contain a limiting
16 amplifier and the optical source would be driven into a
17 power maximum condition, rather than linearly controlled,
18 as the source is extremely non-linear in nature.

19

20 Electronic signal ewave 25 shows all rising edges 19, or
21 all falling edges 20 can be independently extended or
22 reduced in time, represented by dTr 22 or dTf 21
23 respectively, in order to alter the spatial zero crossing
24 and by adding or reducing energy within the transmitted
25 bit patterns. These altered pulse edges can therefore be
26 employed to counter-act artefacts including edge
27 distortion, non-linear rise fall times, duty cycle
28 distortions and laser chirp.

29

30 In addition energy can be added to a transmitted "zero"
31 by temporarily inverting the optical signal 30 so as to
32 insert a short pulse of "one" 17, with duration dTl 23,
33 and energy can be independently removed from a
34 transmitted "one" by temporarily inverting the optical

1 signal 30 so as to inserting a small pulse of "zero" 18,
2 with duration dTh 24. This is a remedy for equalising
3 modal, chromatic and polarisation distortion within the
4 optical fibre or other bandwidth limitations. In so
5 doing the adaptable signal processor 7 stops symbol
6 dependant energy over-spill from one symbol to the next
7 and minimises interference between symbols and removes
8 ISI. The input waveform 1 is thus pre-distorted by the
9 adaptable signal processor 7. This technique is most
10 appropriate to optical systems because the optical source
11 either usually incorporates a limiter function in the
12 optical pre-drive circuitry or the optical source 8 is
13 operated at near maximum photonic energy output or is so
14 non-linearly compressed so as to act like a limiting
15 function. It is therefore only the existence of the
16 electronic signal ewave 25 above or below the zero-cross
17 discrimination point and not the signal amplitude that
18 warrants attention and suitably exploited when
19 synthesising this equaliser.

20
21 Figure 6 shows the time-domain input and output waveforms
22 in a communications system employing this invention. The
23 figure shows the synthesised electronic signal ewave 25
24 and the now less distorted output signal 5 after
25 equalisation has been employed. Note this waveform 25 is
26 for illustrative purposes only and no random jitter is
27 shown and depending on the compensating parameters set
28 the waveform can be more or less equalised.

29
30 Figure 7 shows the resulting improved "eye diagram" of
31 the information presented in Figure 6. The job of the
32 receiver 4 is made far easier because the data jitter 15
33 (normally measured in ps) and the eye closure 16
34 (normally measured in dBs) are greatly improved over that

presented in Figure 4. Hence the sampling point 14 is more easily obtained and tracked than that shown in Figure 4.

Figure 8 shows a preferred embodiment of a circuit schematic of the adaptable signal processor 7. It can be seen to comprise the input signal, in 1, and its synchronous clock "clk" signal 51 which are employed to produce output "ewave" signal 25 from a signal processor 65. The apparatus shows four programmable time delay circuits dT1 52, dT2 54, dT3 56 and dT4 58. The time delay circuits produce four phases of "clk" 51, "clkp1" 53, "clkp2" 54, "clkp3" 57 and "clkp4" 59 that are delayed but synchronous versions of "clk" 51. The time delay circuits are independently controlled by coefficient words Cp1 60, Cp2 61, Cp3 62 and Cp4 63. The coefficient words are stored in a register bank 64 that can be updated and refreshed as appropriate by a micro controller or such scheme. The time delay circuits 52, 54, 56 and 58 can be readily implemented using, for example, unit delay cells, phase interpolation or delay locked loop techniques or any other scheme that allows a signal to be controllably delayed.

Figure 9 shows a particular electronic waveform 25 generated by the adaptable signal processor 7 when employed in its preferred embodiment as an equalising element. Figure 9 further comprises schematic representations of the "clk" signal 51 and the four generated phases "clkp1" 53, "clkp2" 55, "clkp3" 57 and "clkp4" 59. It should be noted that the clocks shown are all shown at full rate, however similar schemes could be derived using sub-rate clocks without departing from the scope of this invention.

1
2 In particular:

- 3 • "clkp1" 53 rising marks the falling edge 20 of the
4 "ewave" signal 25, and can be positioned to rise
5 before or after the edge of the "clk" 51 signal
6 thus supporting pre-emption or postponing of the
7 falling edge 20;
- 8 • "clkp2" 55 rising marks the rising edge 19 of the
9 "ewave" signal 25, and can be positioned to rise
10 before or after the rising edge of the "clk" 51
11 signal thus supporting pre-emption or postponing
12 of the rising edge 19;
- 13 • "clkp3" 57 marks the leading edge of the inversion
14 sub pulses 17 and 18 of the "ewave" signal 25; and
- 15 • "clkp4" 59 marks the trailing edge of the
16 inversion sub pulses 17 and 18 of the "ewave"
17 signal 25.

18
19 As the inversion pulses 17 and 18 are broadened by the
20 action of the clocks so more energy is added or removed
21 from the information carrying signal generated by the
22 optical source 8. A second process for varying the
23 energy within the information carrying signal is achieved
24 by shifting in time the inversion sub pulses 18 and 19
25 through the controlled operation of the clocks. These
26 sub pulses can either be shifted in time towards a rising
27 edge 19 or towards a falling edge 20 so that energy can
28 be accurately removed or added to these edges as
29 appropriate.

30
31 In a preferred embodiment the +ve sub pulse inversion 17
32 and the -ve sub pulse inversion 18 are delimited by the
33 same timing clock edges, namely "clkp3" 57 and "clkp4" 59.
34 It will be appreciated by one skilled in the art that

1 this need not necessarily be the case and in other
2 embodiments, the +ve and -ve inversion sub pulses, 17 and
3 18, could be readily made independently controllable.
4 This could be achieved via the incorporation of
5 additional time delay elements so as to generate
6 additional clocks and appropriate changes to the signal
7 processor 65 in order to include this data dependency.

8

9 Further detail of the signal processing block 65 is
10 presented in Figure 10. In summary:

- 11 • Elements "inv" 114, 116, 110 act to logically
12 invert the signal between their input and their
13 output values;
- 14 • Elements "buf" 115, 109 act to buffer the signal
15 between their input and their outputs, often used
16 as unit delay elements to match "inv" elements for
17 timing purposes;
- 18 • Element "xor" 113 act to logically convert the
19 signal between their input and their outputs, such
20 that the output is only a logic high when one and
21 only one input is logically high;
- 22 • Elements "and" 107, 111, 112 act to logically
23 convert the signal between their input and their
24 outputs, such that the output is only a logic high
25 when both inputs are logically high; and
- 26 • Elements "latch" 100, 101, 102, 103, 104, 105, 106 act
27 to logically convert the signal between their
28 input and their outputs, such that the output is a
29 copy of its input but delayed one clock cycle by
30 the action of the respective clk so as to act as a
31 memory element that latches its input to its
32 output.

33

1 It will again be apparent to those skilled in the art
2 that other elemental logical functions can be used to
3 form equivalent logical functions within Figure 10
4 without departing from the scope of this invention. It
5 should also be noted that latch elements 100, 103 and 105
6 are optional elements, and are incorporated for timing
7 synchronisation purposes only.

8

9 The purpose of the logic elements indicated as Arm A 130
10 is to produce a "pulse" signal 121. Figure 10 shows that
11 the input signals to Arm A comprise the input signal "in"
12 1 and the clock signal "clk" 51. A next sample output
13 $S(n)$ 122, a present sample output $S(n+1)$ 123 and a
14 previous sample output $S(n+2)$ 124 are the outputs from
15 the latches 100, 101 and 102, respectively in response to
16 clock signal "clk" 51. The internal "pulse" signal 121
17 is thus generated whenever two identical consecutive pre-
18 ceding bits in $S(n+1)$ 123 and $S(n+2)$ 124 are detected,
19 shown here generated by the "xor" function of element 113
20 and inversion in "inv" 114 in order to produce the
21 correct pulse signal 121.

22

23 The purpose of Arm C 132 is to produce a pulse'' signal
24 129 so providing a means for generating sub pulses 17 and
25 18. Arm C 132 comprises elements 109 "buf" employed to
26 provide a delay element to match that introduced by
27 element "inv" 110. Element 111 "and" acts so as to
28 create a shortened gating pulse pulse' 128 as defined by
29 the edges of "clkp3" 57 and "clkp4" 59, and the
30 coincidence of their high periods. The shortened pulse
31 pulse'' 129 is then produced from the output of element
32 "and" 112 under the gating control of the internal pulse
33 121 employed here as a control signal. The pulse'' 129
34 gating signal is therefore data dependant, as determined

1 by Arm A 130, and thus the sub pulse are data dependently
2 controlled so as to either allow normal 17 or inverted 18
3 sub pulses to be multiplexed by "mux" 108 onto on the
4 electronic signal ewave 25. In so doing bit symbols can
5 be temporarily inverted and electronic equalisation
6 provided without any requirement for normal amplitude
7 modulation techniques being employed to the optical
8 signal 30.

9
10 The purpose of Arm B 131 is to produce an $S(n+1)'''$
11 signal 127 and so provide a means for varying the rising
12 19 and falling edges 20. Arm B 131 comprises latch
13 elements 104 and 106 that act to transfer the data from
14 the controlled phase delayed clock signals "clkp1" 53 and
15 "clkp2" 55 respectively in order to advance or retard the
16 timing edges in the signals $S(n+1)'$ 125 and $S(n+1)''$ 126.
17 Logical "and" element 107 provides the logical function
18 to produce the new signal $S(n+1)'''$ 127, which contains
19 identical data to $S(n+1)$ 123 except that its rising and
20 falling edges have been manipulated by the action of
21 "clkp1" 53 and "clkp2" 55. Element 116 "inv" provides a
22 logical inversion and element 115 "buf" provides a time
23 delay buffer to match the delay introduced by "inv" of
24 116. Subsequent modification is done by "Mux" 108 which
25 outputs electronic signal ewave 25 as either normal or
26 inverted copies of the signal $S(n+1)'''$ under control of
27 the pulse'' 129 signal.

28
29 The synthesised input electronic signal ewave 25 is shown
30 in Figure 5 showing rising edges 19, or falling edges 20
31 that can be extended or reduced in time, of dTf 21 or dTr
32 22 respectively, and energy removed from a "zero" by a
33 short pulse of "one" 17, with duration dTl 23, and energy
34 removed from a "one" by inserting a small pulse of "zero"

1 18, with duration dTh 24. However in alternative
2 embodiments not all features of the method are required
3 to be employed such that the edge time extension or
4 reduction effects and/or the sub pulse insertion effects
5 can be used to lesser degree, or completely removed. An
6 associated reduction in the required apparatus to
7 implement these solutions would then occur. Particular
8 alternative embodiments can be achieved by:

9

- 10 1) Excluding Arm B 131 so that no edge modifications
11 are possible. In this embodiment the signal
12 $S(n+1)'''$ 127 would be provided directly by the
13 $S(n+1)$ 123 signal;
- 14 2) Excluding within Arm B 131 elements 103 and 104,
15 that control the rising edge of electronic signal
16 ewave 25, or 105 and 106, that control the falling
17 edge of electronic signal ewave 25. In this
18 embodiment only rising or falling edge
19 modifications respectively are possible and
20 requires the signal $S(n+1)'$ 125 or $S(n+1)''$ 126 to
21 be replaced by $S(n+1)$ 123, as appropriate;
- 22 3) Excluding within Arm C "clkp3" 57 and "buf" 109
23 and replacing with "clk" 51 so that the rising
24 edge of pulse'' 129 is determined directly by
25 "clk" 51 and is not controllable.
- 26 4) Excluding within Arm C "clkp4" 59 and "inv" 110
27 and replacing with "clk" 51 so that the falling
28 edge of pulse'' 129 is determined directly by
29 "clk" 51 and is not controllable.

30

31 In a further alternative embodiment the width of the sub
32 pulses 17 and 18 can be applied independently to either
33 the high or low signals within the data sequence. This is
34 achieved by replacing the "xor" 113 with parallel "and"

1 and "nand" functions so producing two signals, namely
2 "pulse_h" and "pulse_l". The "pulse_h" and "pulse_l"
3 signals can then be used with a simple modification to
4 Arm C 132 so as to accommodate the additional pulse
5 selection via an additional selection element ("and" or
6 "mux") that selects the signal pulse's origin as
7 being for a high (pulse_h) or low (pulse_l) data
8 sequence. Additional clock phases would then be required
9 in order to separately control the rising and falling
10 edges of this additional selection of data dependant sub
11 pulses.

12
13 Figure 11 more clearly shows the signal timing and
14 logical relationships within the signal processing
15 apparatus of Figure 10 and illustrates the scheme from
16 the serial input signal "in" 1 to the electronic signal
17 ewave 25.

18
19 Using the above signal processing scheme a time-domain or
20 z-transform filter function is therefore effectively
21 synthesised where the energy of any bit is a function of
22 what has previously been sent. Expressing this in normal
23 z-domain sampled data convention.

24
25
$$Y(z) = X(z) * H(z)$$

26
27 where:

28 $Y(z)$ is the relative energy of the output
29 sample

30 $X(z)$ is the relative energy of the input sample

31 $H(z)$ is the filter transfer function

32
33
$$H(z) = A(1 - Bz^{-1})$$

34

1 where:

2 A = (Ts-dTf-dTr)

3 B = 1/(Ts+dTf+dTr-dTl) for transmitted zeros

4 or

5 = 1/(Ts-dTf-dTr-dTh) for transmitted ones

6

7 and where:

8 Ts= symbol bit period

9 dTl = pulse inversion period for
10 transmitted zeros

11 dTh = pulse inversion period for
12 transmitted ones

13 (as defined in Figure 9)

14

15 It should be noted that this z-domain technique does not
16 completely describe the action of the filter invention as
17 it does not describe how energy can be shifted within one
18 sample.

19

20 The described method and apparatus effectively provides a
21 non linear (signal dependant) 1st order high frequency
22 bandpass filter. By employing additional previous and
23 future sample information through the incorporation of
24 additional "latch" elements, and by using additional
25 "xor" logical elements or similar structures, higher
26 order high frequency band pass filters can readily be
27 achieved.

28

29 It will be obvious to one skilled in the art that by
30 altering the timing of the various clock pulses the
31 adaptable signal processor can be converted so as to act
32 as a low frequency bandpass filter, the order of which is
33 dictated by the number of "latch", or similar elements,
34 incorporated within the circuit.

1
2 The apparatus of Figure 8 and 10 the signal processor
3 uses no filter function to determine the $S(n+1)'''$
4 signal. However, this can readily be made data dependant
5 and filters can be readily implemented by using a variety
6 of logical schemes such as used to generate the pulse
7 121.

8
9 Furthermore the apparatus of Figure 8 and 10 suggests
10 that the signals are single bit digital lines. In
11 practice they would most likely be differential signals
12 with differential source coupled logic cells. These
13 figures also suggest that the signals are only one bit
14 wide but similar architecture using multiple bit wide
15 parallel data lines could be used in high bandwidth
16 systems with time-interleaving appropriately used for
17 improved power trade-offs.

18
19 Aspects of the present invention described herein refer
20 to a single channel communications system. However, in
21 alternative embodiments, more channels can be employed,
22 such as in a multi-core optical fibre or multi-strand
23 twisted-pair e.g. CAT-5 cabling. The described aspects
24 also refer to a communication system with a single
25 channel with a single transmission signal present on the
26 channel. However, in some embodiments, transmissions can
27 be across one or more shared media channels using one or
28 more signals such as, but not limited to, optical wave
29 division multiplexing schemes (DWDM, CWDM), using
30 multiple equalisers per signal.

31
32 The preferred embodiment of the present invention
33 describes use mainly within the context of a fibre optic
34 medium, however it is anticipated that it may be employed

1 with alternative transmission medium including, but not
2 limited to, over air, optical fibre, printed circuit
3 board or cable. Similarly aspects of the present
4 invention may employ alternative transmission signal
5 formats including, but not limited to, modulated, un-
6 modulated, return to zero coding, non return to zero
7 coding, encoded data, non encoded data, multi-level,
8 binary, continuous or discontinuous, framed, burst or
9 packet based or any combination of these. Furthermore,
10 aspects of the present invention may employ alternative
11 transmission technique including, but not limited to,
12 electrical, electro-magnetic, magnetic or optical means.

13
14 The apparatus of aspects of the present invention present
15 the transmitter 2 and the receiver 4 as two separate
16 elements or components. Alternative embodiments that
17 comprise multiple channel and bi-directional systems that
18 incorporate transmitters and receiver that are joined or
19 part joined within the same combined element or component
20 of the system with the equaliser possibly additionally
21 contained within.

22
23 The described apparatus further describes that the
24 transmitter 2 is a distinct and separate element made up
25 of two parts, the adaptable equaliser 7 and the optical
26 source 8. However, alternative embodiments are envisaged
27 where the transmitter element may also include a
28 combination of additional separate, not necessarily
29 distinct elements in any combination or form, such as a
30 parallel to serial data converter, clock-data recovery
31 unit, re-synchroniser, line driver, equaliser, optical
32 source driver and the optical source itself.

33

1 Further alternative embodiments of aspects of the present
2 invention include the communications system containing
3 additional filters, transducers, amplifiers, sensors or
4 other elements or components between multiple or single
5 transmitters, receivers and medias. In addition the
6 communication system could contain continuous or separate
7 sections of media, separated by filters, transducers,
8 sensors, transponders, transceivers, transmitters,
9 receivers or other elements so as to break the media into
10 one or more sections of not necessarily the same type of
11 media.

12
13 The input signal 1, synthesis electronic signal ewave 25,
14 optical wave owave 26 and apparatus presents a solution
15 to a single binary on-off coding scheme. However, the
16 principle can be applied to similar waves that are
17 encoded in multiple levels such as a pulse amplitude
18 modulation scheme (PAM encoding) and signal processing
19 provided using a similar method.

20
21 In systems where the output amplitude can also be also
22 directly influenced by the instantaneous amplitude of the
23 ewave signal 25, additional equalisation can be applied
24 using an amplitude modulation technique or the
25 superposition of an additional pulse onto the ewave
26 signal as appropriate to increase the energy of the
27 signal in the frequencies of interest. A superposition
28 technique such as analogue summation could be used.

29
30 Described herein is a method and apparatus for adapting
31 an information carrying signal within of before an
32 associated transmitter. This adaptation provides an
33 efficient way of not only producing frequency dependent
34 filters but also provides an effective means for the

1 equalisation of the information carrying signal. The
2 transmitter effectively equalises by providing a pre-
3 correction or compensation of the signal. As a result
4 the transmitter based equalisation schemes described is
5 capable of achieve higher performance than other prior
6 art systems where equalisation takes place within the
7 receiver or elsewhere in the channel. This effect is a
8 direct result of the fact that this system can be
9 designed so that the desired information carrying signal
10 can be kept above the noise or other interference levels
11 and hence can be more easily interpreted at the receiver.
12 Furthermore, as the transmitter has an intrinsically
13 accurate knowledge of what it is trying to transmit, and
14 given information on what signal impairments exist in the
15 system, more simplistic, intelligent, signal aware
16 schemes such as those described above are possible.

17
18 A significant advantage of the described system is that
19 it is very accurately controllable, has a fine
20 resolution, a wide equalisation range, requires few high
21 performance circuit elements to implement, requires less
22 components or circuitry, requires little additional power
23 and can be designed for low cost and high volume
24 manufacturing than existing known schemes.

25
26 Additionally, because the synthesis technique is more
27 controllable, this invention can provide more
28 sophisticated equalisation or compensation for affects
29 other simple bandwidth limitations such as complex non-
30 linear and signal dependant ones. One practical use of
31 this scheme is in high-speed fibre-optic systems where
32 transmission distances are greatest and channel
33 impairments are complex. Examples of such complex
34 impairments include modal, chromatic and polarisation

1 dispersion and chirp of the optical fibre, saturation and
2 scattering properties of the optical source and
3 asymmetries and bandwidth limitations of the optical
4 transmitter and receiver responses.

5
6 A further advantage of aspects of the present invention
7 is that because both the eye closure 29 per length of
8 media is improved and because the data jitter 28 per unit
9 media is reduced, greater distance can be travelled
10 before complete opto-electronic-opto signal regeneration
11 or re-timing units are required. This greatly benefits
12 the systems because it enables cheaper all optical
13 systems to be made.

14
15 A yet further advantage is that more cost effective,
16 lossy or dispersive media can be used and over greater
17 distances in higher data rate applications. For example,
18 twisted pair could be used where previously coaxial cable
19 would have been required or multi-mode fibre where
20 previously single-mode fibre was used.

21
22 Generally the method and apparatus of aspects of the
23 present invention provide for the development and
24 manufacture of higher performance communications systems,
25 including optical ones, that are less expensive, less
26 complex, less power demanding or more compact.

27
28 The foregoing description of the invention has been
29 presented for purposes of illustration and description
30 and is not intended to be exhaustive or to limit the
31 invention to the precise form disclosed. The described
32 embodiments were chosen and described in order to best
33 explain the principles of the invention and its practical
34 application to thereby enable others skilled in the art

1 to best utilise the invention in various embodiments and
2 with various modifications as are suited to the
3 particular use contemplated. Therefore, further
4 modifications or improvements may be incorporated without
5 departing from the scope of the invention as defined by
6 the appended claims.